Overview of BTeV Physics, the Components and the Requirements

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The Physics: More Specific

- **CP Violation:** Particles behave differently than antiparticles
  - Demonstrated in B decays by BaBar & Belle (one ∠ measured, β)
  - But there are 4 different angles to determine
  - New Physics can show up as inconsistencies between/among CP measurements and other quantities
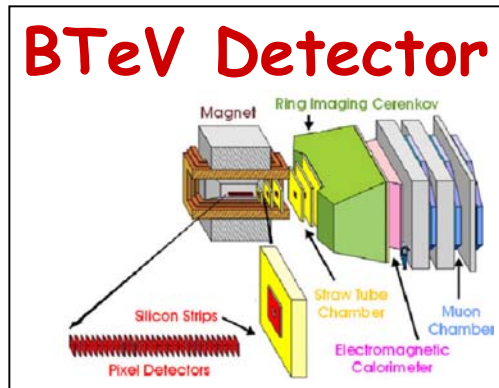
- **Rare Decays**
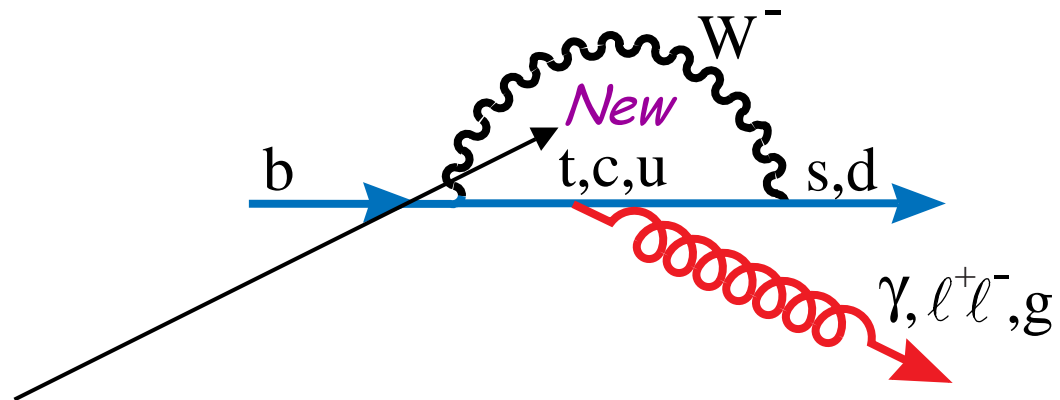
  - New Particles can appear in the loop & interfere

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Project Scope

WBS 1.0
BTeV Detector

WBS 3.0
CO Hall Outfitting

WBS 4.0
BTeV Project

WBS 2.0
CO Interaction Region

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Requirements on C0 IR

- Peak Luminosity $\sim 2 \times 10^{32}$ cm^{-2} s^{-1} ($\beta* < 50$ cm)

- Interoperability: Must allow for operation at C0 or at B0 & D0 simultaneously

- Non-interference with BTeV detector – last quadrupole closest to collision point is 5 m further away than in CDF or D0

- Schedule: Must be ready by shutdown in middle of 2009

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- Building already exists

- We need to

  - Provide the architectural, structural, mechanical and electrical work for the BTeV detector (WBS 1.0).

  - Provide the modifications to the C-0 Service Building and primary power for the Interaction Region (WBS 2.0).

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BTeV Collaboration

Belarussian State- D .Drobychev, A. Lobko, A. Lopatrik, R. Zouversky

UC Davis - P. Yager

Univ. of Colorado at Boulder
J. Cumalat, P. Rankin, K. Stenson

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J. Appel, E. Barsotti, C. Brown, J. Butler, H. Cheung, D. Christian, S. Cihangir, M. Fischler, I. Gaines, P. Garbincius, L. Garren, E. Gottschalk, A. Hahn, G. Jackson, P. Kasper, P. Kasper, R. Kutschke, S. W. Kwan, P. Lebrun, P. McBride, J. Slaughter, M. Votava, M. Wang, J. Yarba

Univ. of Florida at Gainesville
P. Avery

University of Houston –
A. Daniel, K. Lau, M. Ispiryan, B. W. Mayes, V. Rodriguez, S. Subramania, G. Xu

Illinois Institute of Technology
R. Burnstein, D. Kaplan, L. Lederman, H. Rubin, C. White

Univ. of Illinois- M. Haney, D. Kim, M. Selen, V. Simatis, J. Wiss

Univ. of Insubria in Como-
P. Ratcliffe, M. Rovere

INFN - Frascati- M. Bertani, L. Benussi, S. Bianco, M. Caponero, D. Collona, F. Fabri, F. Di Falco, F. Felli, M. Giardoni, A. La Monaca, E. Pace, M. Pallota, A. Paolozzi , S. Tomassini

INFN - Milano – G. Alimonti, P'Dangelo, M. Dinardo, L. Edera, S. Erba, D. Lunesu, S. Magni, D. Menasce, L. Moroni, D. Pedrini, S. Sala , L. Uplegger

INFN - Pavia - G. Boca, G. Cossali, G. Liguori, F. Manfredi, M. Maghisoni, L. Ratti, V. Re, M. Santini, V. Speviali, P. Torre, G. Traversi

IHEP Protvino, Russia - A. Derevschikov, Y. Goncharenko, V. Khodyrev, V. Kravtsov, A. Meschanin, V. Mochalov, D. Morozov, L. Nogach, P. Semenov K. Shestermanov, L. Soloviev, A. Uzunian, A. Vasiliev

University of Iowa
C. Newsom, & R. Braunger

University of Minnesota
J. Hietala, Y. Kubota, B. Lang, R. Poling, A. Smith

Nanjing Univ. (China)-
T. Y. Chen, D. Gao, S. Du, M. Qi, B. P. Zhang, Z. Xi Xang, J. W. Zhao

New Mexico State -
V. Papavassiliou

Northwestern Univ. -
J. Rosen

Ohio State University-
K. Honscheid, & H. Kagan

Univ. of Pennsylvania
W. Selove

Univ. of Puerto Rico
A. Lopez, H. Mendez, J. Ramierez, W. Xiong

Univ. of Science & Tech. of China - G. Datao, L. Hao, Ge Jin, L. Tiankuan, T. Yang, & X. Q. Yu

Shandong Univ. (China)-
C. F. Feng, Yu Fu, Mao He, J. Y. Li, L. Xue, N. Zhang, & X. Y. Zhang

Southern Methodist –
T. Coan, M. Hosack

Syracuse University-
M. Artuso, C. Boulahouache, S. Blusk, J. Butt, O. Dorjkhaidav, J. Haynes, N. Menaa, R. Mountain, H. Muramatsu, R. Nandakumar, L. Redjimi, R. Sia, T. Skwarnicki, S. Stone, J. C. Wang, K. Zhang

Univ. of Tennessee
T. Handler, R. Mitchell

Vanderbilt University
W. Johns, P. Sheldon, E. Vaandering, & M. Webster

University of Virginia M. Arenton, S. Conetti, B. Cox, A. Ledovskoy, H. Powell, M. Ronquest, D. Smith, B. Stephens, Z. Zhe

Wayne State University
G. Bonvicini, D. Cinabro, A. Schreiner

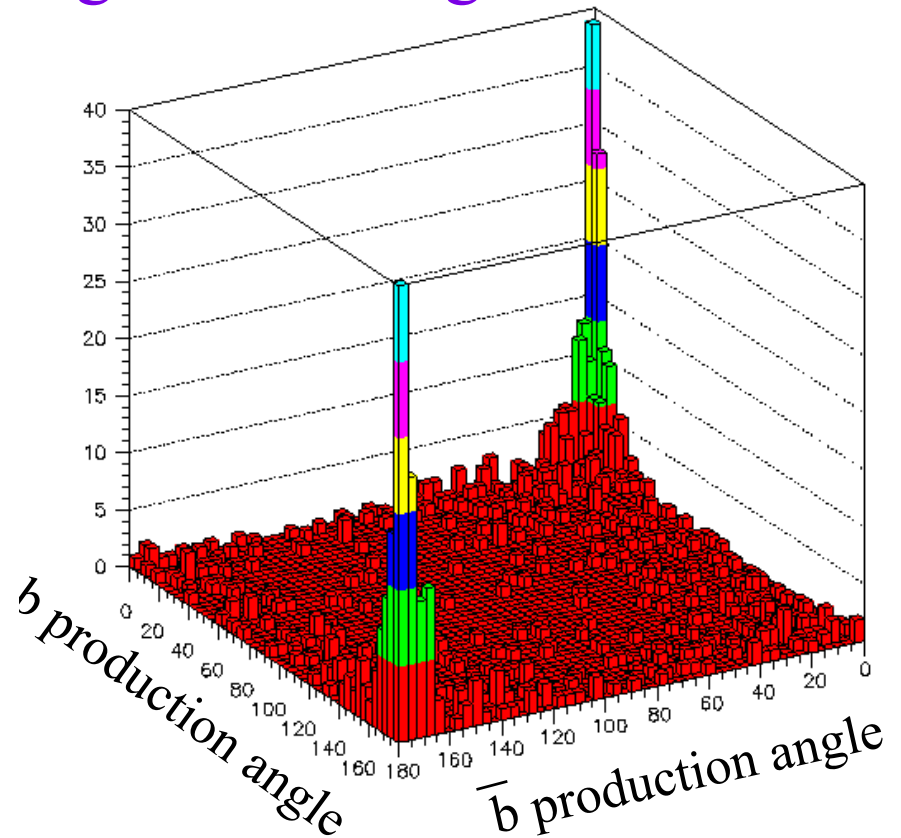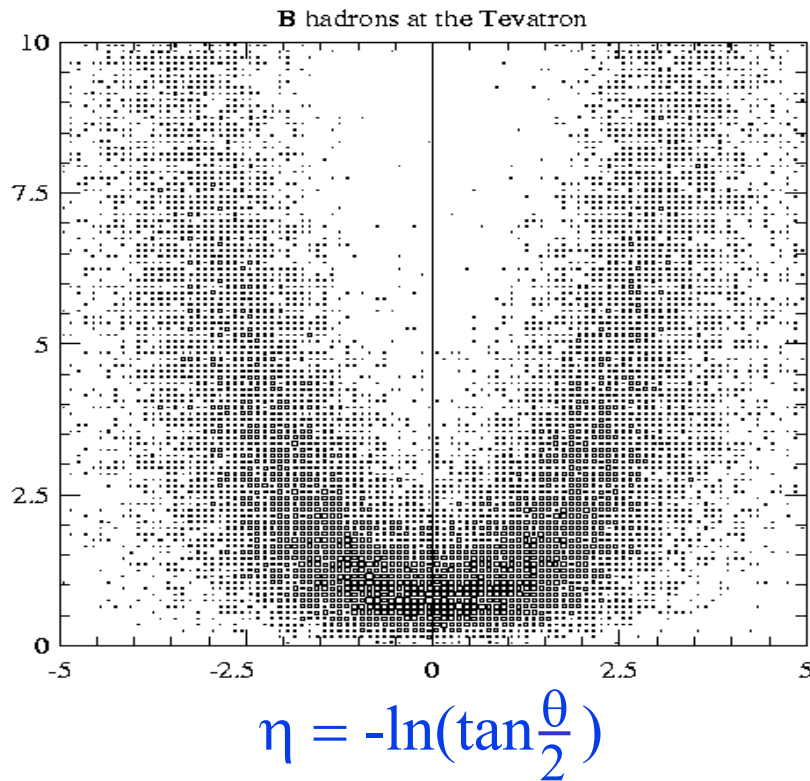**University of Wisconsin**
M. Sheaff

York University - S. Menary

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$$p\bar{p}\rightarrow b\bar{b}+X$$

The higher momentum b's are at larger η's

b production peaks at large angles with large b̄b correlation

B hadrons at the Tevatron

$\beta\gamma$

$$\eta = -\ln(\tan\frac{\theta}{2})$$

b production angle

b̄ production angle

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Requirements: General

- Intimately tied to Physics Goals

- In general, within the acceptance of the spectrometer (10 – 300 mr with respect to beam) we need to:

  - Detect charged tracks & measure their 3-momenta
  - Measure the point of origin of the charged tracks (vertices)
  - Detect neutrals & measure their 3-momenta
  - Reveal the identity of charged tracks (e, μ, π, K, p)
  - Trigger & acquire the data (DAQ)

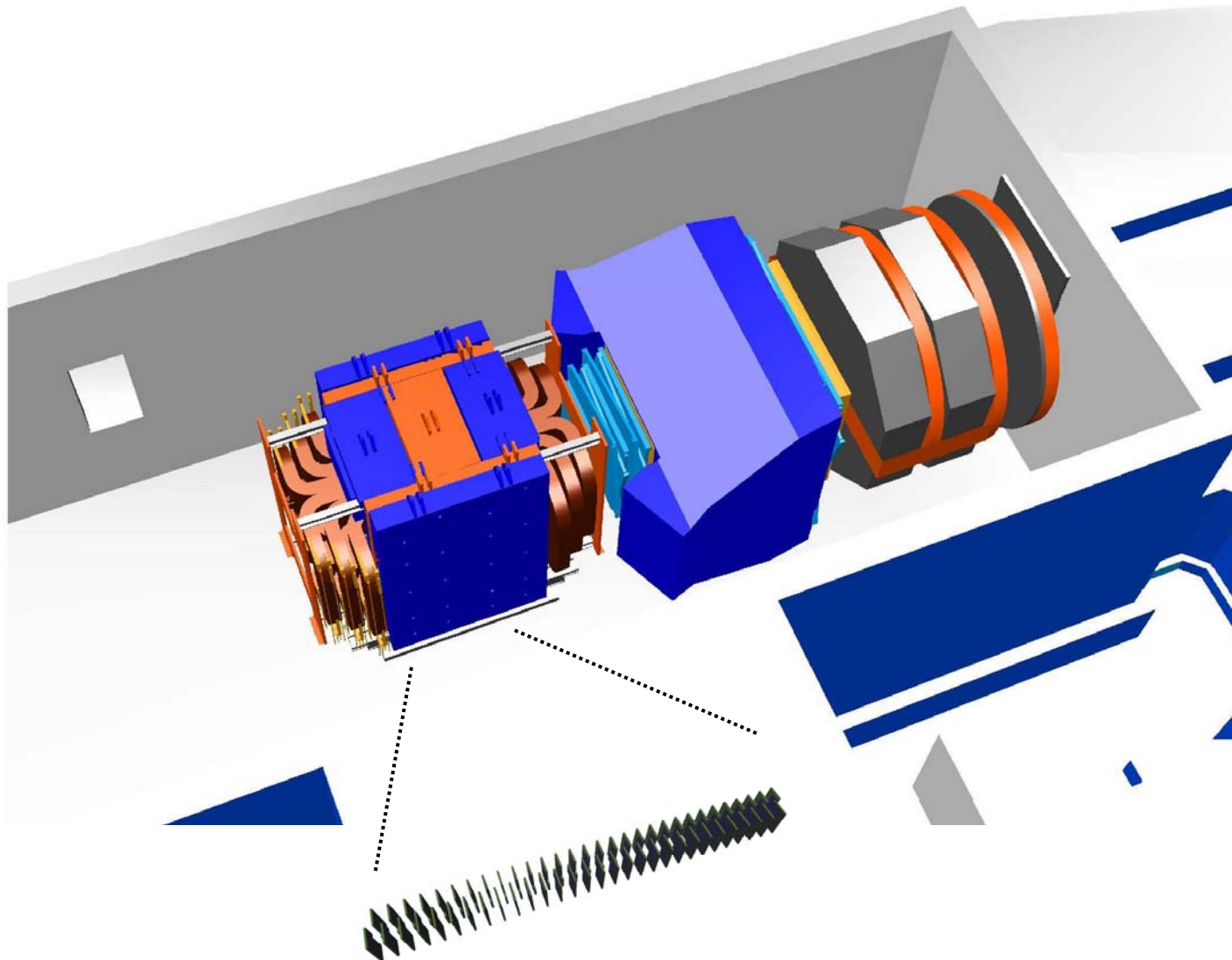- Detector we designed meets the requirements

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Basics Reasons for the Requirements

- B's (& D's) are long lived, ~1.5 ps, so if they are moving with reasonable velocity they go ~3 mm before they decay. This allows us to <u>Trigger</u> on the the presence of a B decay (*detached vertex*).

- B's are produced in pairs $p\bar{p} \rightarrow b\bar{b} + X$, and for many crucial measurements we must detect one b fully and some parts of the other: "flavor tagging"

- Physics states of great interest now are varied and contain both charged modes and neutrals, B_d & B_s

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More Basic Reasons
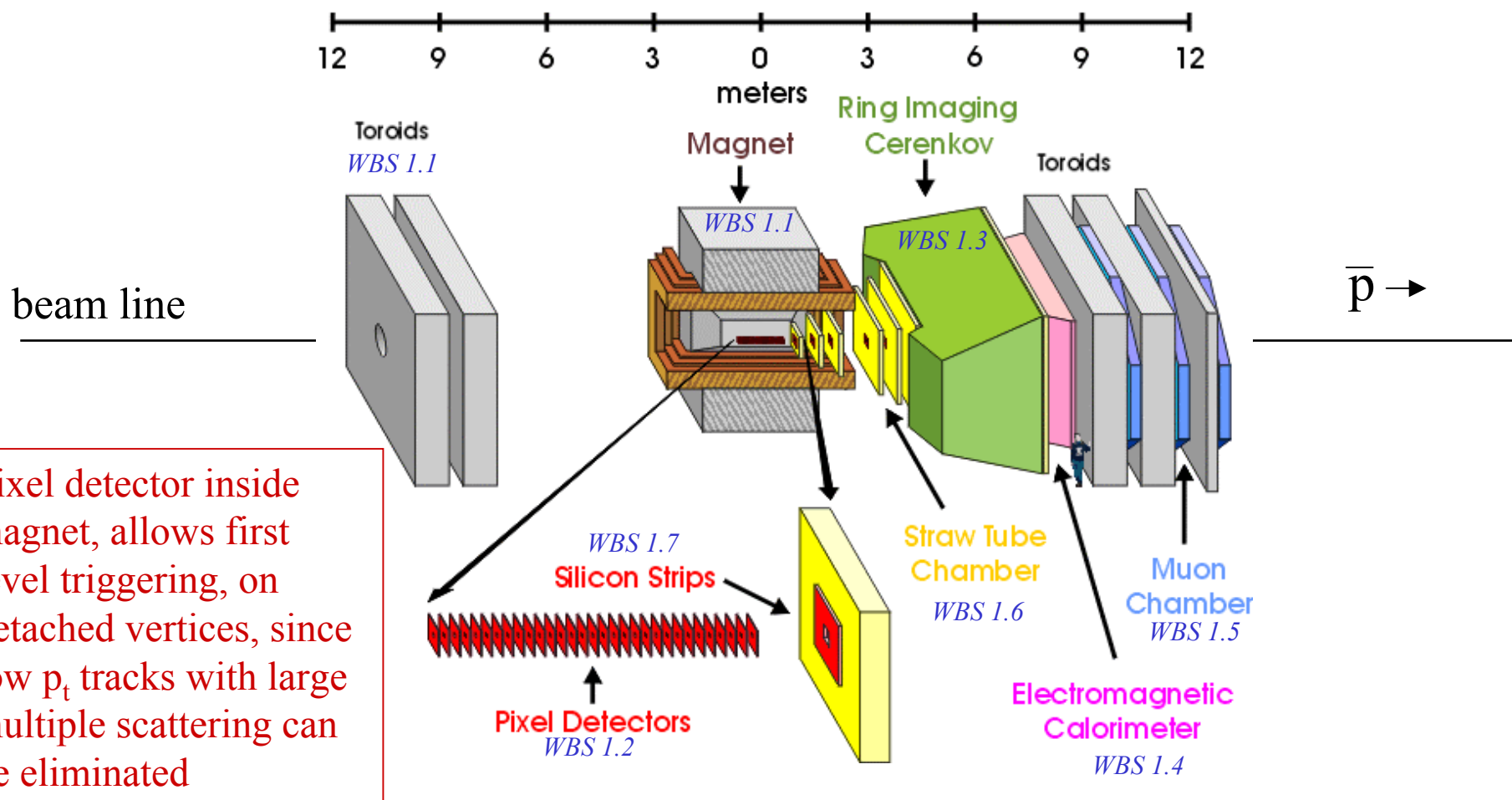
- Many modes contain γ, π^o & η, so need excellent electromagnetic calorimetery

- B_s oscillations are fast, so need excellent time resolution $\sim <50$ fs, compared to ~ 1500 fs lifetime. Also very useful to reduce backgrounds in reconstructed states

- Physics Backgrounds from $\pi \Leftrightarrow K$ can be lethal
  - $B_s \rightarrow D_s \pi^-$ is 15X $B_s \rightarrow D_s K^-$
  - $B^o \rightarrow K^* \pi \rightarrow K^\mp \pi^\pm \pi^o$ is 2X $B^o \rightarrow \rho\pi \rightarrow \pi^+ \pi^- \pi^o$
  - So excellent charged hadron identification is a must

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The BTeV Detector

BTeV Detector Layout

Pixel detector inside magnet, allows first level triggering, on detached vertices, since low p_t tracks with large multiple scattering can be eliminated

beam line

$\overline{p} \rightarrow$

meters

Toroids
WBS 1.1

Magnet
WBS 1.1

Ring Imaging Cerenkov
WBS 1.3

Toroids

WBS 1.7
Silicon Strips

Pixel Detectors
WBS 1.2

Straw Tube Chamber
WBS 1.6

Muon Chamber
WBS 1.5

Electromagnetic Calorimeter
WBS 1.4

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- **Excellent decay time resolution**
  - ➤ Reduces background
  - ➤ Allows detached vertex trigger

ψ from b

direct ψ

L/σ

L/σ

- **The average decay distance and the uncertainty in the average decay distance are functions of B momentum:**

$\langle L \rangle = \gamma\beta c\tau_B$
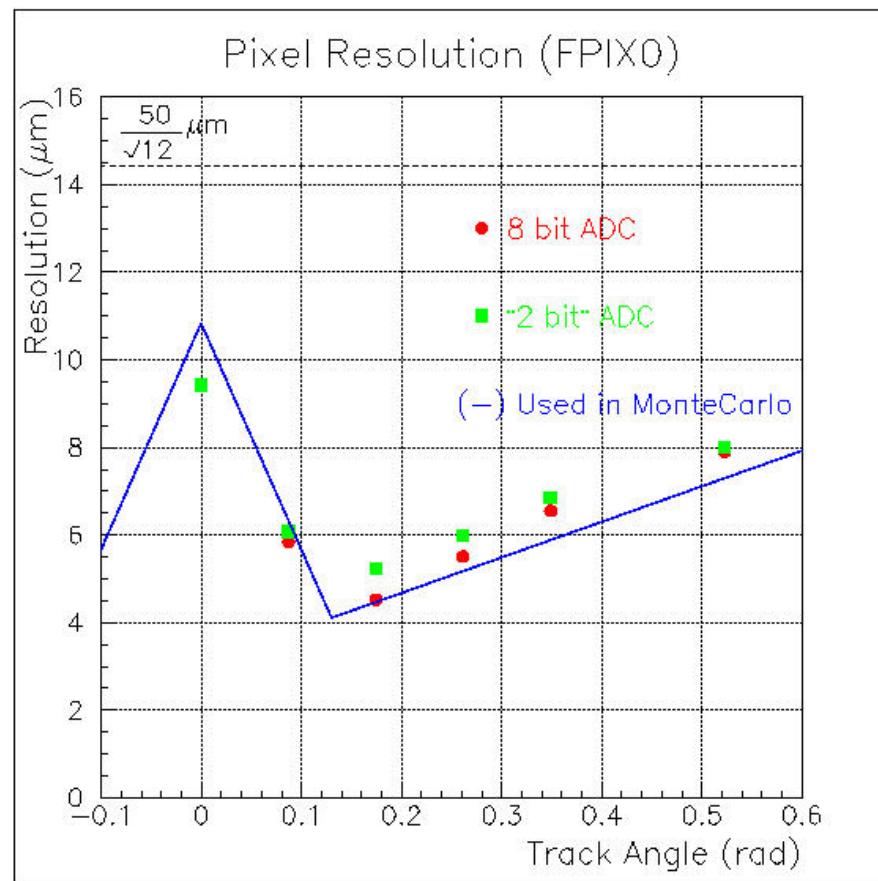
$= 480\ \mu m \times p_B/m_B$
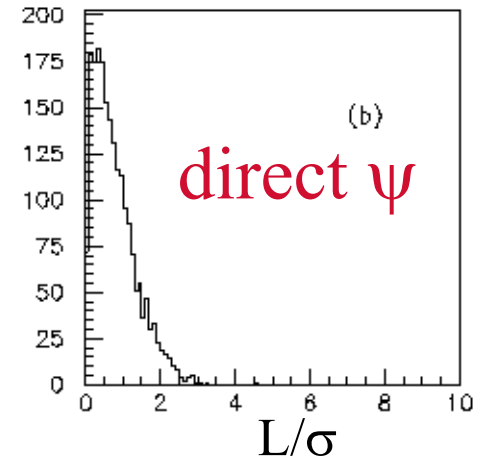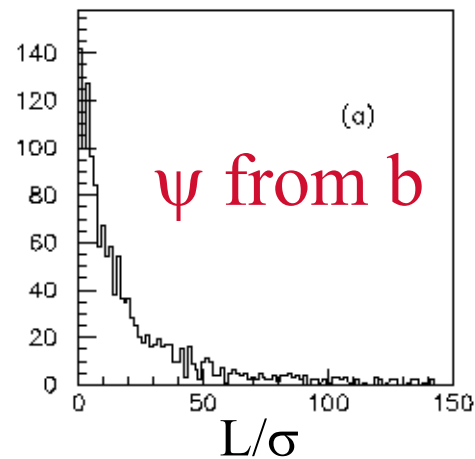
CDF/D0 region →

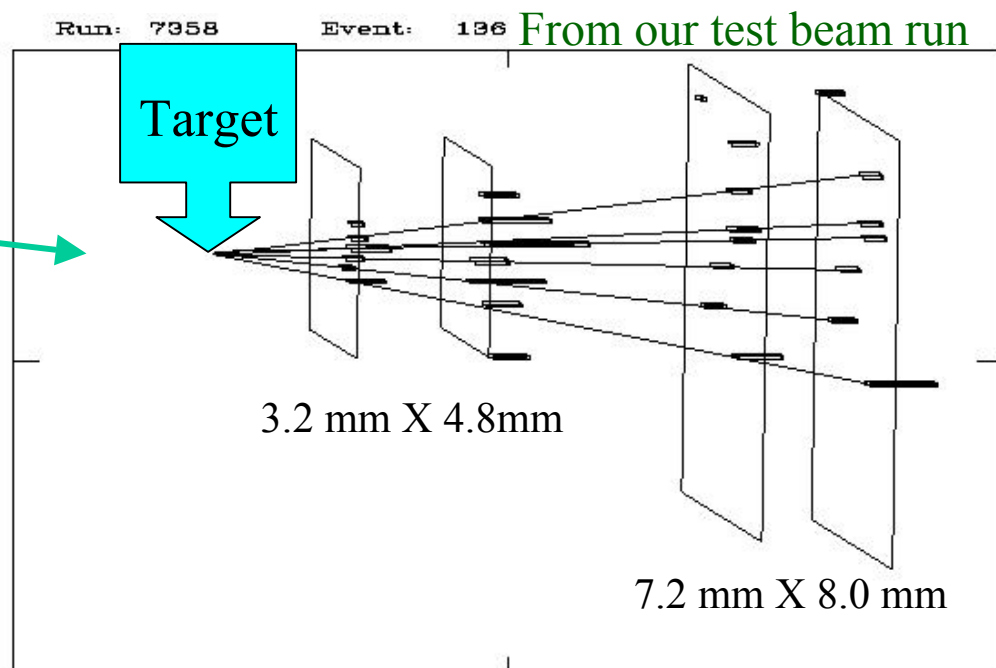↖ LHC-b region

Pixels *(WBS 1.2)*

- Pixel – working systems studied in beams, including "almost" final electronics

- Full mechanical design done and being tested

- Pixels are inside of beam pipe in machine vaccum – OK with accelerator provided the outgassing rate is below specified limits (review document linked to Review web page)

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Physics Simulations Tools

- Full GEANT has multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight; smears hits and refits the tracks using "Kalman Filter." No pattern recognition (except for trigger). However, we do not expect large pattern recognition problems

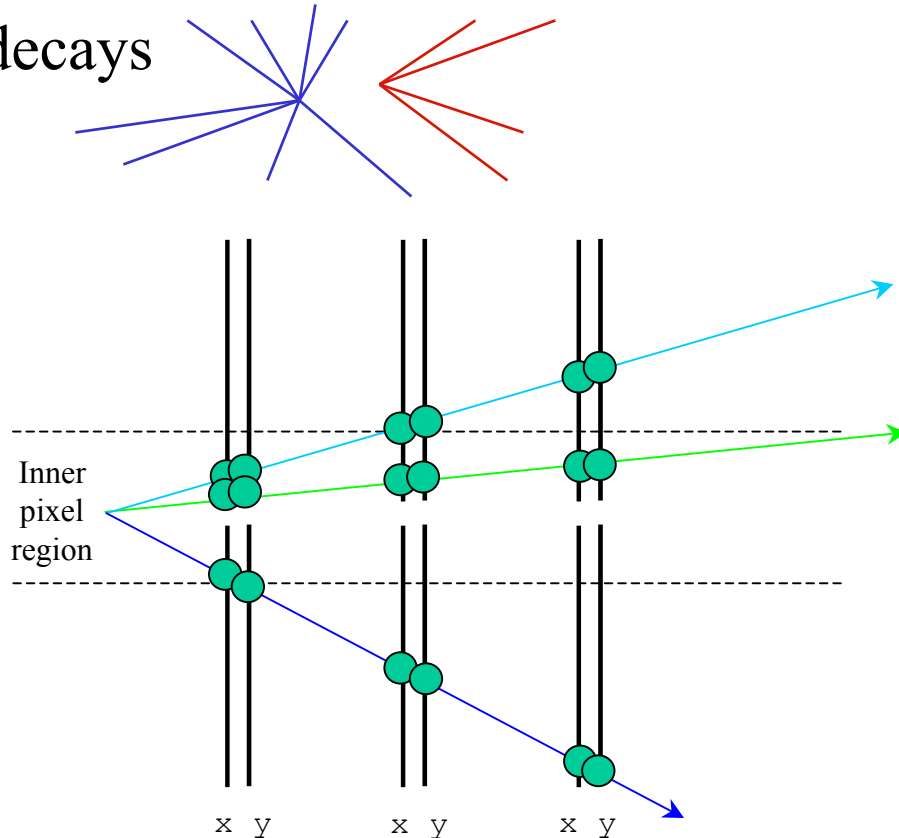• **This track density is 3x higher than what is expected in BTeV!**

◆Detailed studies of efficiency and rejection for up to an average of six interactions/crossing

Run: 7358   Event: 136   From our test beam run

Target

3.2 mm X 4.8mm

7.2 mm X 8.0 mm

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Pixel Trigger Overview *(WBS 1.8)*

◆ Idea: find primary vertices & detached tracks from b or c decays

- Pixel hits from 3 stations are sent to an FPGA tracker that matches "interior" and "exterior track hits

- Interior and exterior triplets are sent to a farm of DSPs to complete the pattern recognition:

  • interior/exterior triplet matcher

  • fake-track removal

Inner pixel region

x y   x y   x y

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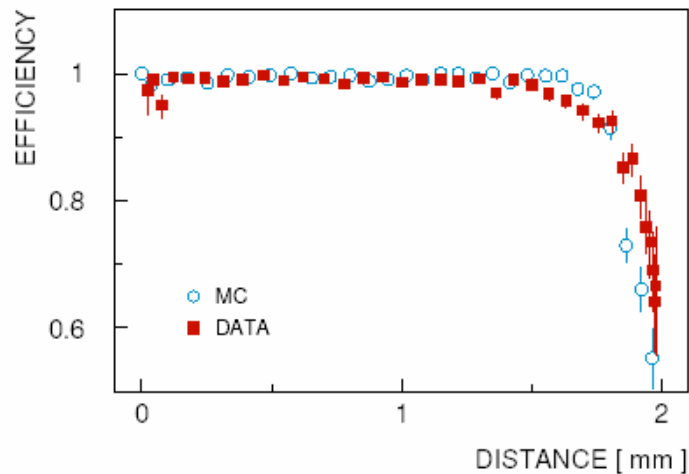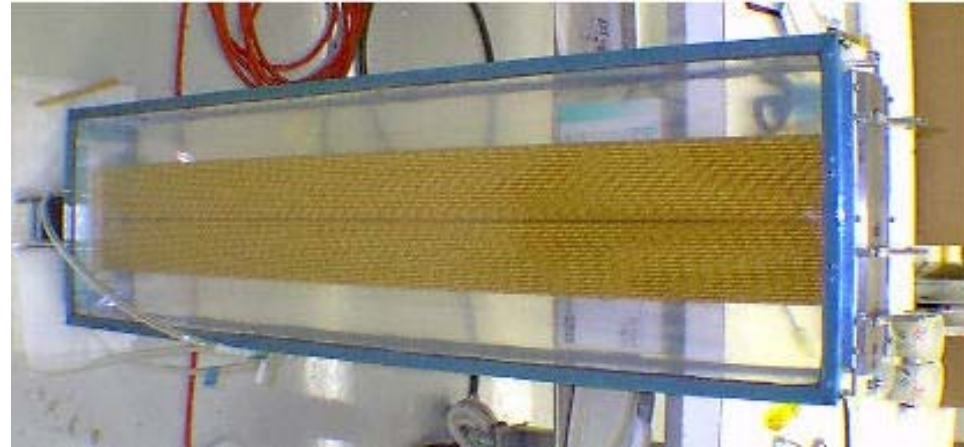
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Trigger Performance

- For a requirement of at least 2 tracks detached by more than 4σ, we trigger on only 1% of the beam crossings and achieve the following efficiencies for these states at Level I:

State	efficiency(%)	state	efficiency(%)
$B \rightarrow \pi^+\pi^-$	55	$B^o \rightarrow K^+\pi^-$	54
$B_s \rightarrow D_s K$	70	$B^o \rightarrow J/\psi\, K_s$	50
$B^- \rightarrow D^o K^-$	60	$B_s \rightarrow J/\psi K^*$	69
$B^- \rightarrow K_s\pi^-$	40	$B^o \rightarrow K^*\gamma$	40

@ 2 int/crossing

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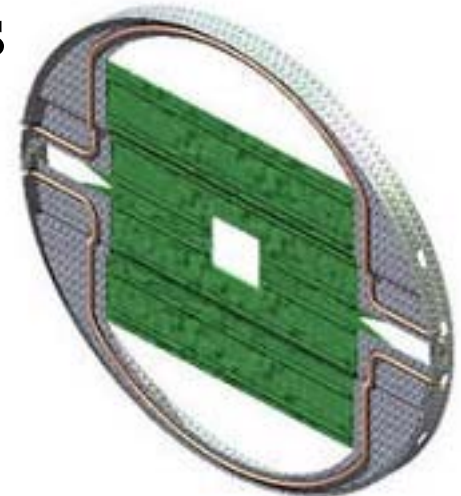
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Tracking

- Straws *(WBS 1.6):*

  protoype undergoing tests, uses Atlas design as basis

- Straw test beam using $Ar(80\%)/CO_2(20\%)$

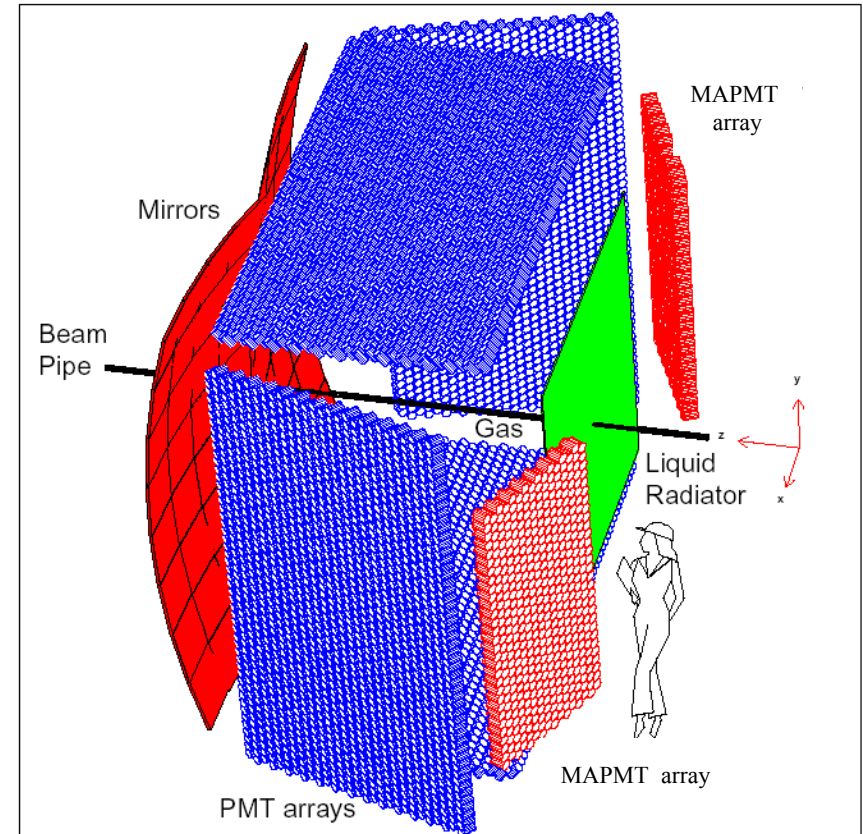

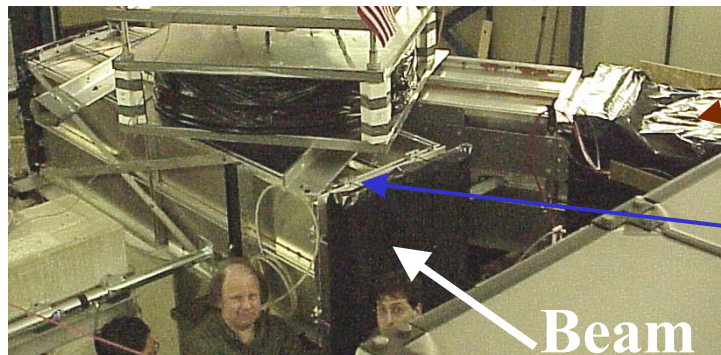- Silicon Strips *(WBS 1.7):* simple single sided design, mechanics done.

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- Gas + Mirror + MAPMT to identify b decay products

- Liquid + PMT's to help with flavor tagging of b's (p/K separation for p < 9 GeV/c)

- Excellent particle id. distinguishes BTeV from "Central pp Detectors"

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RICH Test Beam

BTeV/Co

MAPMT array →

C$_4$F$_8$O radiator

Beam

σ_γ =

0.94 mr

MC=

0.86 mr

Cherenkov Ring

$\Theta\gamma - \Theta_{exp}$ (mrad)

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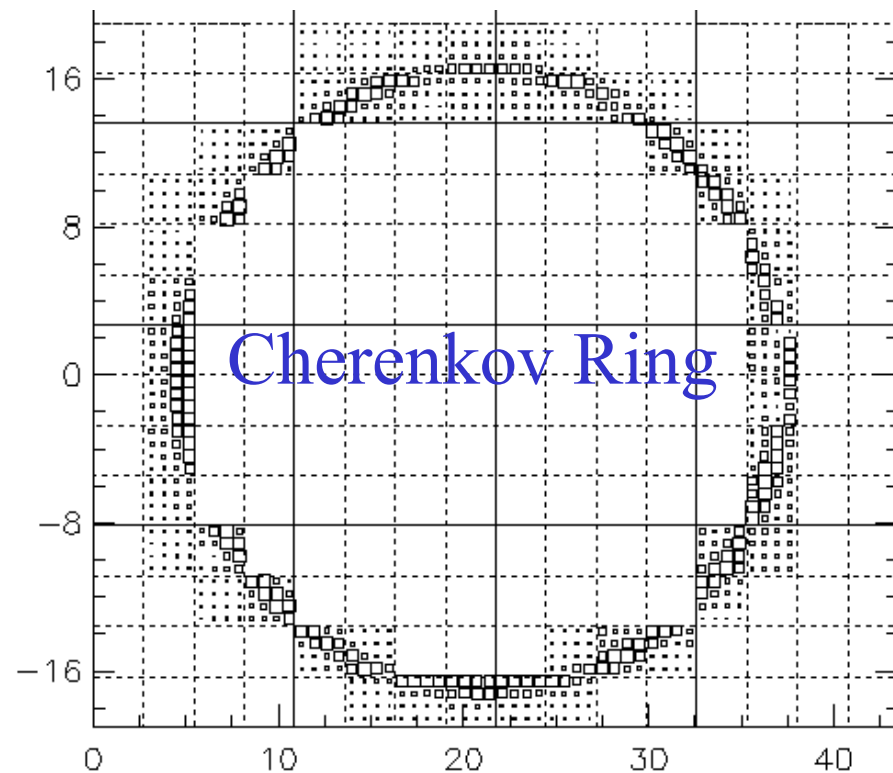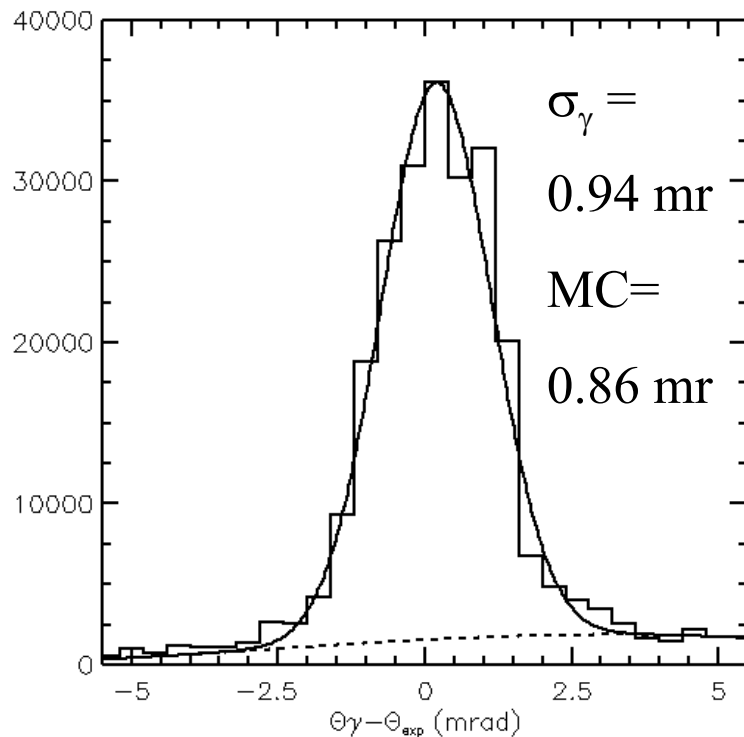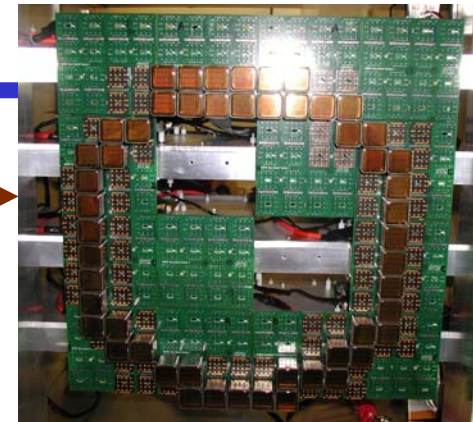
EM cal *(WBS 1.4)* using PbWO$_4$ Crystals

- Use CMS development of crystal technology. Now used for CMS, ALICE, JLAB, etc…

- Use Photomultiplier tubes instead of APD's

- Extensive Test Beam program at Protvino

Energy Resolution

Fit function = a ⊕ b/√E ⊕ c/E

a = 0.33±0.02 %
b = 1.8±0.1 %
c = 2.4±0.2 %

Radiation Damage

a) Bogoroditsk
14 rad/h
17 rad/h
22 rad/h
12 rad/h

b) 15 rad/h
12 rad/h
13 rad/h
18 rad/h
Apatity (filled)
Shanghai (open)

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B⁰→ρπ
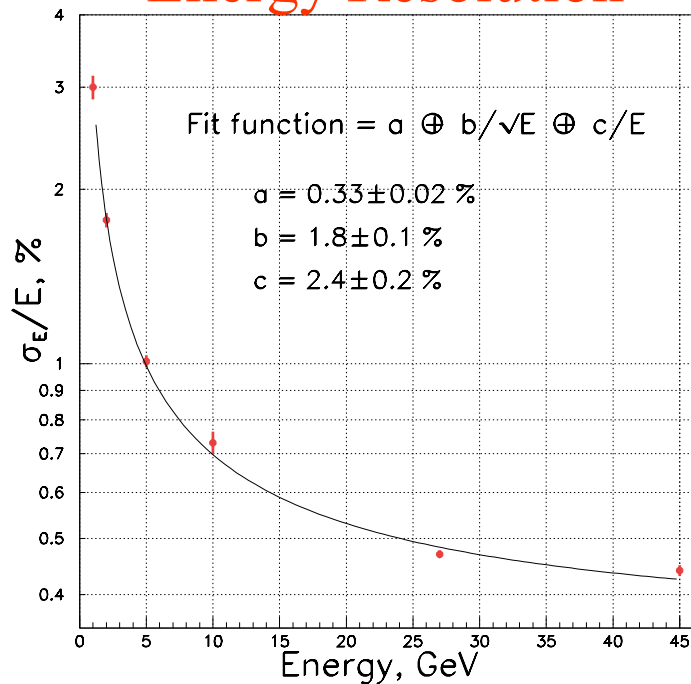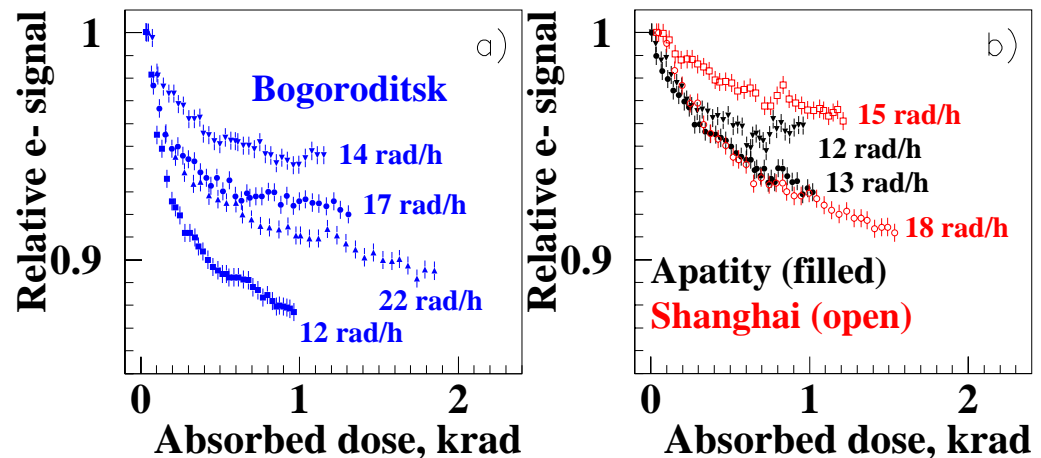
Based 9.9×10^6 bkgrnd events

$B^o \rightarrow \rho^+ \pi^-$ S/B = 4.1

$B^o \rightarrow \rho^o \pi^o$ S/B = 0.3

bkgrnd

signal

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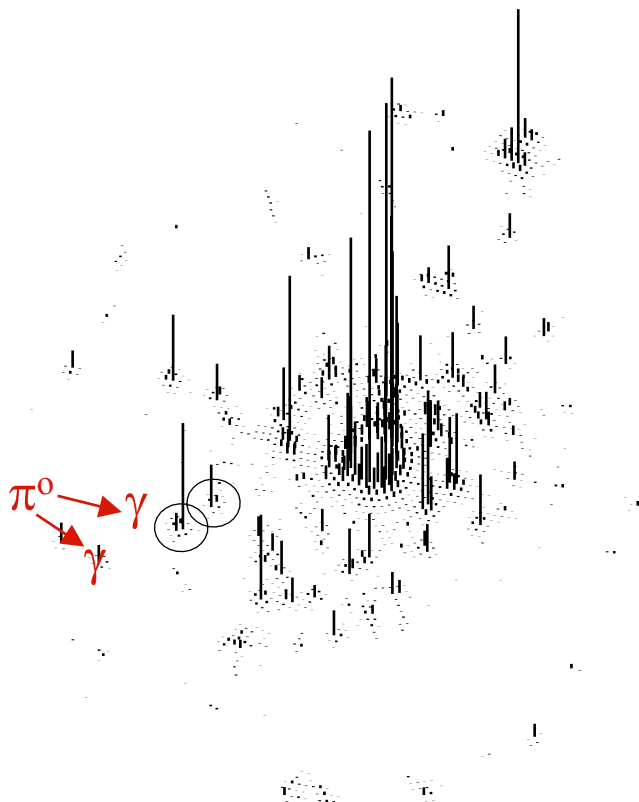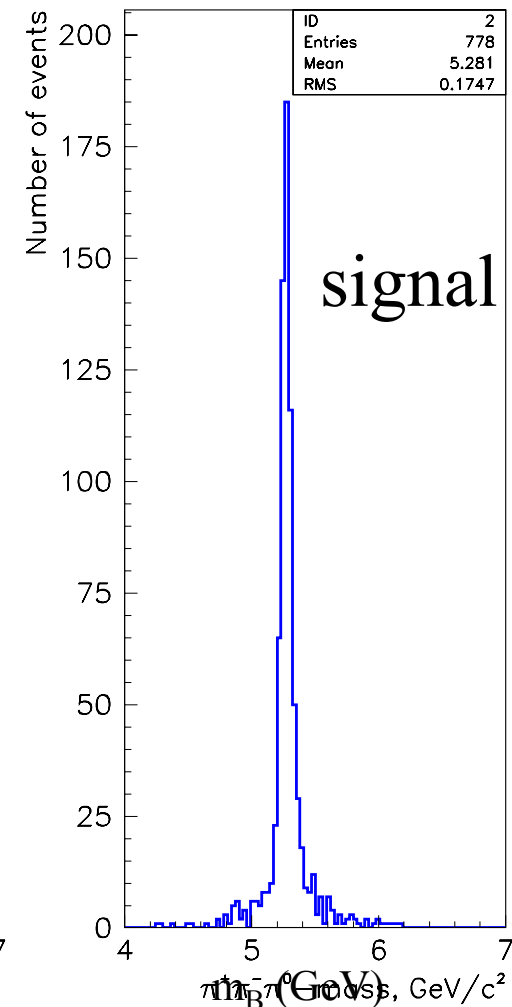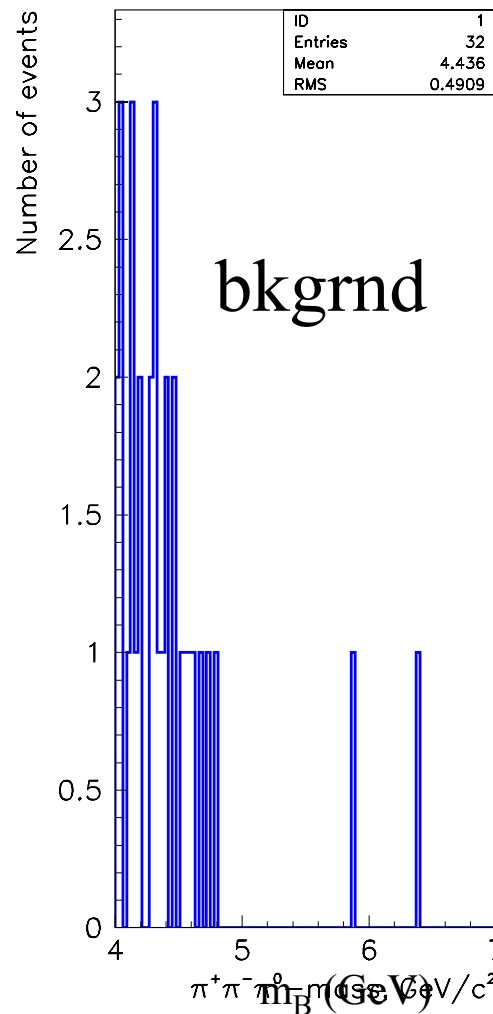
Muon System *(WBS 1.5)*

- Used to check detached vertex trigger by having an independent di-muon trigger

- Also used for μ id

- Tested in beams

- Robust design: stainless steel tubes, already tested in beams

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Kinds of Requirements

- One set of requirements is based on the physics performance we want the detector to provide

- A second set is internal to the detector subsystem of interest and tells how each individual piece needs to perform (i. e. the efficiencies of PM tubes, or noise on electronics)

- I will concentrate on the first set here

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Fundamentals

- Luminosity up to 2×10^{32} cm^{-2}s^{-1}

- Mean number of interactions per crossing of 6 (thus allowing for 396 ns bunch spacing)

- Time between bunches < 100 ns (thus allowing for 132 ns bunch spacing)

- Radiation Resistance for at least 10 years on all detector components

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High Level Requirements

- ## Charged Tracks

  - Angular acceptance: 10 - 300 mr
  - $p > 3$ GeV/c
  - Tracking efficiency > 98%
  - Mass resolution < 50 MeV/c
  - Primary vertex resolution (along beam) < 100 μm

- ## Trigger efficiency & rejection

  - $\varepsilon > 50$ % for all B decays with ≥ 2 charged tracks
  - $\varepsilon > 20$ % for all B decays with 1 charged track
  - Trigger rejection > 98% on light quark events (Level I), and 99.9% at Level III with only a 10% further loss in b efficiency
  - Maximum data rate to archival storage < 200 Mbyte/sec

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Hadron & Lepton Identification

- π/K separation ≥4σ for momenta 3 - 70 GeV/c

- p/K separation ≥3σ for momenta 3 - 70 GeV/c

  ➢ These allow for π/e & π/μ separation at 4σ level up to ~23 and ~17 GeV/c, respectively

- positive μ identification from 5 - 100 GeV/c with a fake rate < 10^{-3} and an independent momentum determination with resolution

$$\frac{\sigma_p}{p} = 19\% \oplus 0.6\% \times p$$

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- Radius up to 160 cm ~220 mr, with hole for beam ~10 mr

- Range E > 1 GeV

- Energy resolution

$$\frac{\sigma_E}{E} < \frac{2\%}{\sqrt{E}} \oplus 1\%$$

- Position resolution

$$\sigma_x < \frac{4\ \text{mm}}{\sqrt{E}} \oplus 1\,\text{mm}$$

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Physics Reach (CKM) in 10^7 s

Reaction	$\mathcal{B}(B)(\times10^{-6})$	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8°
$B^o \to J/\psi\, K_S$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13°
$B^- \to K_S \pi^-$	12.1	4,600	1		$< 4^o$ +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	$\sim 4^o$
$B_s \to J/\psi\, \eta,$	330	2,800	15		
$B_s \to J/\psi\, \eta'$	670	9,800	30	$\sin(2\chi)$	0.024

Just because a mode isn't listed, doesn't mean we can't do it!

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Endorsements & Schedule

- BTeV was included as a near term priority in the category of "Highest Scientific Importance and Near-term Readiness for Construction," in the "Facilities for the Future of Science: A Twenty-year Outlook" report of the Office of Science.

- Based on our physics sensitivities, and **implementation in 2009** a HEPAP subpanel wrote: "**P5** supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, **we strongly recommend an earlier BTeV construction profile** and enhanced C0 optics"

- *Presidents FY2005 Budget Request: "The BTeV experiment will have scientific competition from a dedicated B physics experiment at the CERN LHC, so timely completion of BTeV is important."*

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Endorsements

- BTeV was included as a near term priority in the category of "Highest Scientific Importance and Near-term Readiness for Construction," in the "Facilities for the Future of Science: A Twenty-year Outlook" report of the Office of Science

- P5 originally wrote: "P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area."

- From the recent P5 report: "Given our analysis, we find that our conclusions of last year are unchanged in the staging scenario proposed by BTeV and we reaffirm these conclusions. The method of staging chosen by BTeV is an appropriate choice to maximize their physics opportunities"

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The End

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Overview of BTeV Physics, the Components and the Requirements –Sheldon Stone

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